

The Influence of Naturally and Artificially
Elevated Levels of Sodium in Drinking
Water on Blood Pressure in School Children

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THE INFLUENCE OF NATURALLY AND ARTIFICIALLY ELEVATED LEVELS OF SODIUM IN DRINKING WATER ON BLOOD PRESSURE IN SCHOOL CHILDREN¹

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Building on prior work on sodium (Na) in drinking water and its effects on blood pressure (BP), two variations of the initial University of Massachusetts studies were carried out in other locations using the same methodology as the original investigations. A Texas/Oklahoma study compared the BP of 7th graders in two economically similar communities whose drinking water Na levels were 25 mg/L and 275 mg/L, a difference 2½ times that in the original University of Massachusetts studies. A second study in Ohio, within only one community, compared the BP's of the 7th graders with a home water softener to their peers drinking the same water unsoftened (400 ppm total hardness). Although both studies have some complicating factors, the preliminary results indicate some effect of elevated Na in drinking water upon blood pressure in normotensive children.

INTRODUCTION

The preliminary findings of two further studies of the sodium (Na) in drinking water and blood pressure (BP) hypothesis are reported in this paper. Since an earlier paper in this volume reviews the evidence for such a link, a consideration of the literature is not included here (Calabrese *et al.*, 1980).

During the senior author's one year leave of absence at the Health Effects Laboratory of the U.S. Environmental Protection Agency it was possible to undertake two field studies not originally in our University of Massachusetts five year programmatic research plan. The first study was a dose response replication comparing children's blood pressure in two communities with a large difference in drinking water sodium levels. This work was carried out in

¹These investigations were funded and conducted as inhouse studies while Dr. Tuthill was on a one year I.P.A. leave with E.P.A.

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Texas and Oklahoma (Texhoma study). The second investigation was designed to assess whether there was any effect of home water softeners on children's blood pressure, and was carried out in an Ohio community (Ohio Water Softener study).

The field work for the studies was carried out during the period April-June 1979. Seventh grade students were examined in both studies. Our earlier Massachusetts work showed an association between Na levels in drinking water and Bp levels for both tenth graders and third graders (Calabrese and Tuthill, 1980). Seventh graders were chosen for the new studies because the possible problem of differential illicit drug use as among the tenth graders could be somewhat avoided while at the same time the administrative problems connected with working in a large number of different schools would be reduced. Both of the investigations were funded as inhouse studies in the Environmental Protection Agency.

The methodology used for recording blood pressures was as carefully structured as in the earlier Massachusetts studies. Four nurses were selected from a larger pool on the basis of a blood pressure training film. They were then carefully standardized in technique and accuracy against a more highly trained nurse by the use of a dual stethoscope. Each child's blood pressure was taken by three different nurses in consecutive order. No nurse could see the blood pressures recorded by the earlier nurses. The same nurses were used to record blood pressure in both communities in the Texhoma study. Likewise another group of nurses examined both the children with home water softeners and those without in the Ohio investigation. The nurses were not informed as to which group was exposed to the high Na levels in drinking water. However, due to newspaper publicity it is possible that some of the nurses in the Texhoma study knew which community had the high Na levels. In the Ohio water softener study, the nurses were completely unaware of which children had the home water softeners.

THE TEXHOMA STUDY

This study was designed to compare the blood pressure distributions of seventh graders from two socioeconomically matched communities with a large difference in sodium levels in their drinking water. The Texas community had a drinking water sodium level of 275 mg/L while the Oklahoma community's sodium level was only 25 mg/L. The difference in sodium levels between the communities was 250 mg/L compared to only a 100 mg/L difference in the original Massachusetts studies, or 2½ times greater. Thus it was possible to assess whether an increased dose of sodium in drinking water resulted in a greater upshift of blood pressure among healthy children.

ADMINISTRATIVE

It took a considerable period of time to locate the communities finally selected for study. The search for a high Na drinking water community started close to Cincinnati, in Ohio, Kentucky, and Indiana and then branched out to

encompass a geographical area with the highest levels of sodium occurring naturally in geological strata: the states of Texas and Oklahoma. Community size was another important factor with the communities considered being between 20,000 and 40,000 in population. This size range provided sufficient children from one grade level and at the same time reduced the political complexities found in larger metropolitan areas. The Texas high sodium community chosen was in the Northern area of the state with a half dozen possible comparison communities of similar size nearby (by Texas standards). A second almost perfectly matching Texas community was located as a possible control but subsequently declined to participate in the study. The other nearby Texas communities were unsatisfactory matches either from a socioeconomic standpoint or because of middle range sodium levels. An Oklahoma community just across the Texas state border, although not as ideal as the original control, did match satisfactorily. However, the high sodium Texas community had more industry, a somewhat higher growth rate 1970-1978 and was more prosperous than the low sodium Oklahoma control city. Although not apparent in the early planning, the Oklahoma community had a lower birth rate and had fewer seventh graders than at first indicated by the statistics from the school superintendent's office. Table 1 displays relevant matching data.

TABLE 1. Socioeconomic and Workforce Comparison of the High Sodium and Low Sodium Communities - Texhoma Study

Characteristic	Community	
	High Sodium	Low Sodium
Population size	29,000	21,000
% Population change (1960-70)	+16.3	+3.0
Median family income	\$9,000	\$7,500
Median educational level	12.2	12.1
% Black	9.9	11.0
% Spanish speaking	1.0	<1.0
% Unemployed	2.3	3.2
% in Manufacturing	31.6	13.2
% White collar	48.1	52.0
% Government	10.1	13.7
Water sodium levels	285	10

METHODS

The study began by sending home a permission slip to be signed by the parents along with a questionnaire for them to fill out. The questionnaire inquired about family history of hypertension, medical conditions and medication used by the child, salt used in cooking and at the table, source of drinking

water and duration of use, length of residence, and socioeconomic status. The participating students were brought by classroom to the screening area where they were weighed, measured and had their pulse and blood pressure recorded. They also answered questions about recency of last meal and smoking habits. Several weeks later the students completed a 24 hour diet diary and provided a home tap water sample and a first morning urine specimen.

RESULTS

Some three-quarters of the eligible pupils in both school systems had their blood pressure taken, about 85% of these filled out diet histories, about two-thirds brought tap water samples and one-half provided urine specimens. The following preliminary data are restricted to Whites because of the very small numbers of Blacks, Hispanic and American Indians in the study.

The comparisons of blood pressure distributions between the two communities can be noted in Table 2. There are no statistically significant differences in mean blood pressures between communities for either sex for systolic or diastolic pressures. The differences were minimal except for male diastolic where the difference is almost 2 mmHg but in the direction opposite to that hypothesized.

TABLE 2. Mean Systolic and Diastolic Blood Pressure by Sex and Community Group — Texhoma Study

Community	Sodium (ppm)	N	Males		N	Females	
			Syst BP (mmHg)	Dias BP (mmHg)		Syst BP (mmHg)	DIAS BP (mmHg)
High Sodium	285	114	99.0	54.0	114	98.5	57.8
Low Sodium	10	63	98.5	55.9	46	98.4	57.5
Difference	275	—	0.5	-1.9	—	0.1	0.3
p value ¹	—	—	0.39	0.09	—	0.48	0.42

¹t test for difference of means.

However, there is one major methodologic difficulty which clouds the interpretation of these data. In accord with Murphy's Laws, no research can go perfectly. In this case a tornado struck near the low sodium community in the late evening before the morning of the screening. Because of the tornado alert, many children were up part of the night and/or slept in makeshift arrangements in basements or garages. The extent of the problem became apparent only after a substantial number of the children had been screened. The only choice was to continue the screening or to repeat the whole study in two new communities as the high sodium community had already been screened. Therefore, the screening was completed on the low sodium community children.

Murphy's Law can sometimes work in one's favor as well. There were many wells used for the high sodium community's public water supply. The

sodium levels of the wells were uniformly high (250 ppm - 300 ppm), with the exception of two wells at 75-90 ppm sodium. As it turned out, this small well field served one of the two junior highs in the community as well as the homes of half of the students from that junior high. Based upon the home and school tap water samples it was possible to cross-classify all individuals by sodium exposure level at home and at school into one of four groups: Low-Low (LL), High-Low (HL), High-High (HH), and Low-High (LH). The fourth category LH had only a handful of children in it and could not be used in the analysis. Within the high sodium community only, it is thus possible to compare three sub-groups of children with differential drinking water Na level exposures.

Table 3 compares the children within the high sodium community by their home and school Na exposure grouping. For males, the mean systolic BP of the HH group is statistically significantly higher than the other two groups at 7.1 and 4.8 mmHg respectively. For female systolic BP a similar situation exists with a statistically significant difference of 4.8 mmHg between HH and HL groups and 7.6 mmHg between the HH and LL groups. There were not statistically significant differences between groups for diastolic BP for males or females.

It should be especially noted that the above two sets of data are not adjusted for differences between groups in regards to other factors related to blood pressure such as weight, height, heart rate and socioeconomic status. Nor have all individuals who should be excluded for medical reasons etc. been excluded. Since the two junior highs serve quite different socioeconomic populations the adjustment process may have an important effect and the current differences may disappear or get larger. Dietary sodium intake and urinary sodium excretion also remain to be considered as well as differences in other characteristics of the drinking water.

THE OHIO WATER SOFTENER STUDY

The second study, in Ohio, was designed to assess whether home water softeners had an effect on children's blood pressure. The basic strategy was to compare seventh graders who lived in houses with home water softeners to

TABLE 3. Mean Systolic and Diastolic Blood Pressure by Sex and Sodium Group Within the High Sodium Community — Texhoma Study

Sodium Group	N	Males		N	Females	
		Syst BP (mmHg)	Dias BP (mmHg)		Syst BP (mmHg)	Dias BP (mmHg)
1. High Home, High School (HH)	51	102.2	54.0	46	102.3	56.8
2. High Home, Low School (HL)	29	95.1	54.2	30	97.5	60.0
3. Low Home, Low School (LL)	34	97.4	54.0	38	94.7	57.4
p values for t test for difference of means						
HH versus HL		0.00	0.47		0.01	0.06
HL versus LL		0.16	0.48		0.10	0.09
HH versus LL		0.02	0.49		0.00	0.38

their peers drinking the same water unsoftened. Home water softeners generally involve a Zeolite exchange system using sodium chloride. They achieve softening by replacing 1 part of hardness as calcium carbonate by .46 of a part of sodium. Since the study community public drinking water was distributed at 400 ppm hardness and had a sodium level of only 10 ppm, a one-hundred percent efficient home water softener could add up to 184 mg/L of sodium raising the drinking water sodium level to 194 mg/L.

METHODS

Fortunately, it was possible to locate a community in Ohio about an hour's drive from Cincinnati which had hard water at 400 ppm and about forty percent of the houses were reported by water softener distributors as having home water softeners. After obtaining the cooperation of the school system, parental permission slips and questionnaires were sent home. Data similar to the previous study including source of water were obtained. In addition, detailed questions were asked about home water softener use. Questions included whether the softeners were hooked up to the hot water only or to hot and cold with the kitchen tap excluded or whether all water was softened. Length of use of the softener and brand name were also requested.

School children were weighed, measured and screened for blood pressure as in the Texhoma Study. The nurses had no way of knowing which children's parents had home water softeners.

RESULTS

Some sixty-three percent of the eligible pupils returned a questionnaire and had their blood pressure taken. As in the Texhoma study a lesser proportion completed diet diaries, turned in home tap water samples and/or provided first morning urine samples.

The water exposure situation turned out to be more complicated than in the Texhoma study. The two largest groups of children received their water from the town distribution system; one group drinking it unsoftened, the other group having a home water softener. A third group lived on a military base which had a separate supply of water softened through zeolite exchange at the base water treatment plant. Another group of pupils on the closest edge of a neighboring town attended school in the study community, but drank water at home softened with lime, a process which did not raise the sodium level. And finally, a small number of students had private wells at home.

The composition of the several groups and their mean blood pressures are shown on Table 4. Town Distribution represents those children drinking town water at 400 ppm hardness or well water with sodium levels below 30. The Town Softener group is children whose homes receive town water but there is a water softener hooked up to the cold water used for cooking and drinking purposes or whose homes have well water similarly treated. Military is the military base group and Next City represents the neighboring city children who attend school in the study community. The military base has sodium levels between 175-251 mg/L while the neighboring city's levels are only 19-23.

TABLE 4. Mean Systolic and Diastolic Blood Pressure^a by Sex and Sodium Group — Water Softener Study

Group	Hardness (ppm)	Sodium (ppm)	N	Males		N	Females	
				Syst BP	Dias BP		Syst BP	Dias BP
Town, Dist. ^c	400	8-27	82	104.1	60.0	104	98.8	63.9
Town, Soft ^b	(>200)	7-254	47	102.9	59.9	27	103.4	64.0
Military	(>200)	175-251	17	98.4	59.3	23	99.4	64.2
Next City	112	19-23	16	98.3	57.0	10	95.8	63.5

^aUnadjusted for differences in height, weight, pulse and socioeconomic factors.^bIncludes private wells.

The key comparison in the table is between the Town Distribution (TD) and Town Softener (TS) groups. For males, the mean systolic blood pressure of the TS group (102.9) is actually 1.2 mmHg lower than the average blood pressure (104.1) for the TD group. The diastolic blood pressures are the same.

For female systolic blood pressure the TS group has a higher average blood pressure of 4.6 mmHg (103.4 minus 98.8), but there is no difference for diastolic blood pressure. The Military and Next City groups are considerably lower in mean systolic blood pressure than either of the town water groups but similar in diastolic blood pressure averages.

These data are still preliminary. The decision still has to be made as to whom should be included in the softened group. There were some interesting disparities between reported water softener usage and the sodium values of home water samples. One person who did not use a home water softener had a sodium level of 185mg/L in his tap water sample. It turned out that this was an apartment dweller and the whole complex had a centrally located softening unit. In two other cases people who had softeners but the same sodium level as the distribution system water indicated upon questioning that although they had the unit for five years, neither used it for several years. This kind of person can be excluded from the softened group. However, there still remain a number of homes with water softeners which are reported to be hooked up to the cold water system and used regularly where the tap water sample has low sodium levels. These homes may have just been at a low in the recharge cycle or there may be other problems. Further investigation of these particular situations is warranted and it may be worthwhile collecting a second tap water sample from these homes as well as inspecting the plumbing to confirm the manner in which the softener connection has been made.

The data need to be analyzed further while controlling for other confounding variables. An especially close look needs to be made at the possible socioeconomic and dietary differences between those with and without home water softeners as well as the characteristics of the home water supply as affected by the home plumbing systems.

SUMMARY

What can we conclude based upon the preliminary results of the two studies? There seems to be partial support for our earlier research in Mas-

sachusetts. In both the Texhoma and the Ohio Water Softener studies female systolic blood pressure appears to show a response to higher sodium levels. For the Texhoma study male systolic blood pressure may be elevated in the HIGH-HIGH group, but there seems to be no effect for males in the Water Softener study. Diastolic blood pressure did not appear to be affected by sodium levels in the drinking water for either sex in either study. However, other confounding variables still need to be controlled for before any definitive statements can be made. Of special importance will be any dietary differences in sodium and potassium intake among the various groups being compared. Whereas the University of Massachusetts study of third graders showed only a third of a gram difference in dietary intake of sodium between the communities studied, there may be much larger differences in dietary intake in these new studies which may be confounding the effect of sodium in the drinking water. The final results of these two studies are yet to be fully determined.

GENERAL ISSUES

In conclusion, a few general comments would seem to be in order:

1. Progress in the study of water constituents as they affect human health will be faster if we start looking at specific water constituents as they affect specific diseases. The study of water hardness and cardiovascular diseases is much less likely to be productive than the same energy invested in an investigation of magnesium, copper and chromium levels and sudden cardiac death. The relationship of sodium in the drinking water and blood pressure is this type of specific study.
2. Studies should be carried out at the individual level of data information rather than at the ecological level where the unit of analysis is a geopolitical unit. A comparison of specific constituents of home drinking water samples among persons ill and not ill from a specific disease is much more informative than comparing the characteristics of the public drinking water systems generally for communities with high and low cardiovascular disease rates. The Texhoma study reported above was a hybrid study where two communities were compared but at the same time data on the individual level was obtained for BP and to allow control for potentially confounding variables—diet, weight, height, and socioeconomic status. In the Ohio water softener study all data were on the individual level.
3. In some cases the effects on physiological parameters of healthy normal populations may be just as valuable, if not more valuable, than the study of special high risk populations or diseased groups. However, it may be sometimes appropriate to study special groups like children where the number of potential confounding variables related to the disease may be lower than for adults.
4. The effects of Na in the drinking water on BP in the Massachusetts studies is greater than the small difference in intake might seem to warrant. There are several other leads which should be investigated. Is some of the Na in food bound up in certain dietary fibers and thus

excreted? Is the Na in liquid form (much like alcohol) metabolized much more rapidly by the body than when combined with food? More rapid absorption would more highly stress the homeostatic mechanisms controlling extracellular fluid levels and other cardiovascular adjustment mechanisms.

5. The association of sodium level in the drinking water to elevation of blood pressure is supportive of a causal relationship but far from definitively proven. We welcome additional studies of this hypothesis by other investigators and will be glad to provide advice.

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